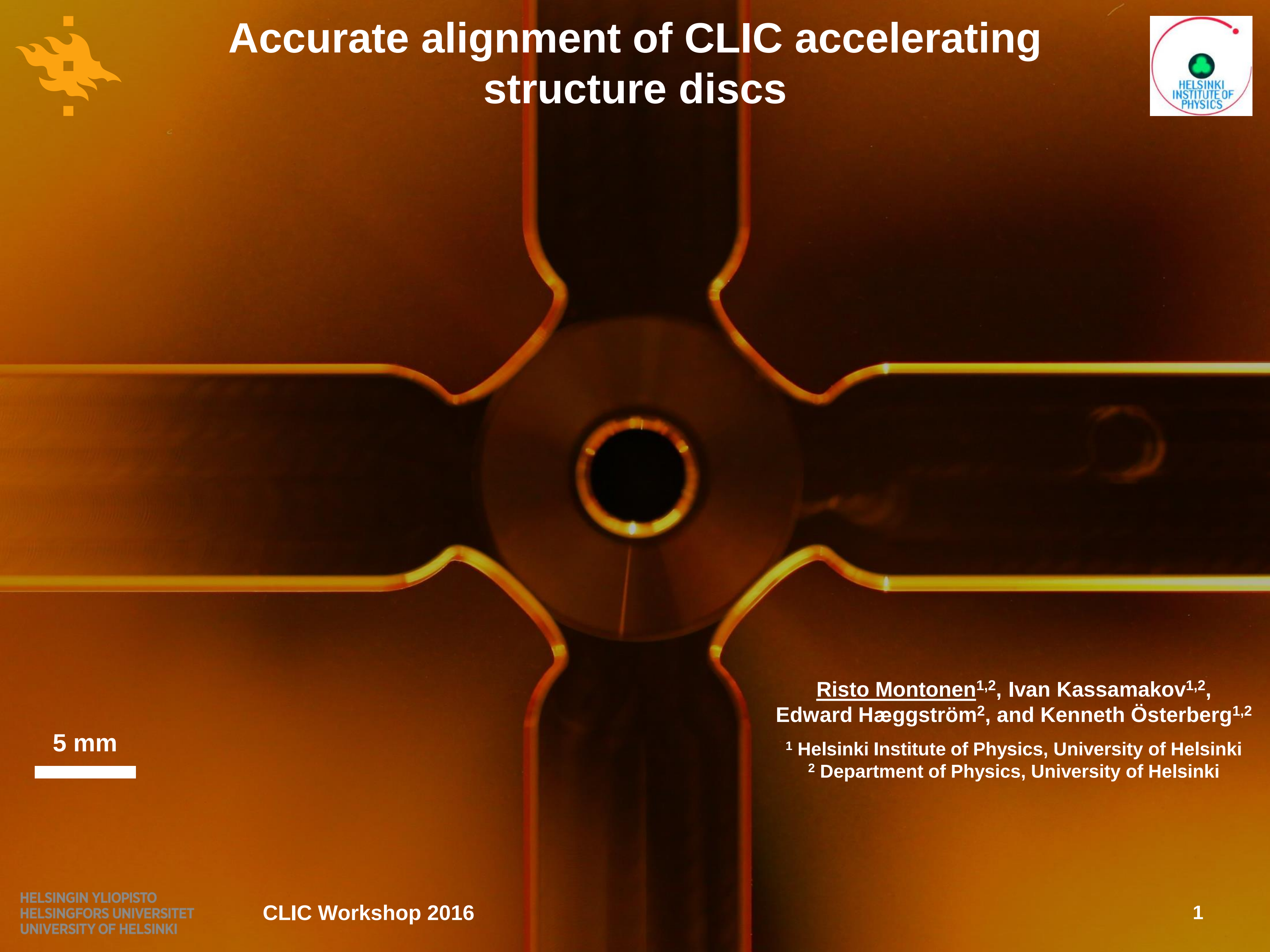
Accurate alignment of CLIC accelerating structure discs



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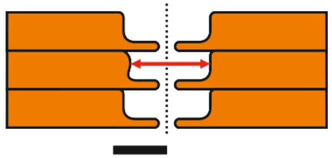
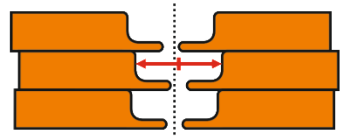
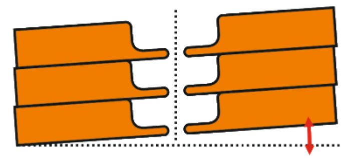
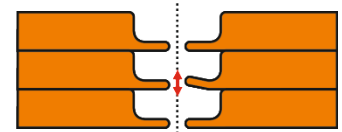
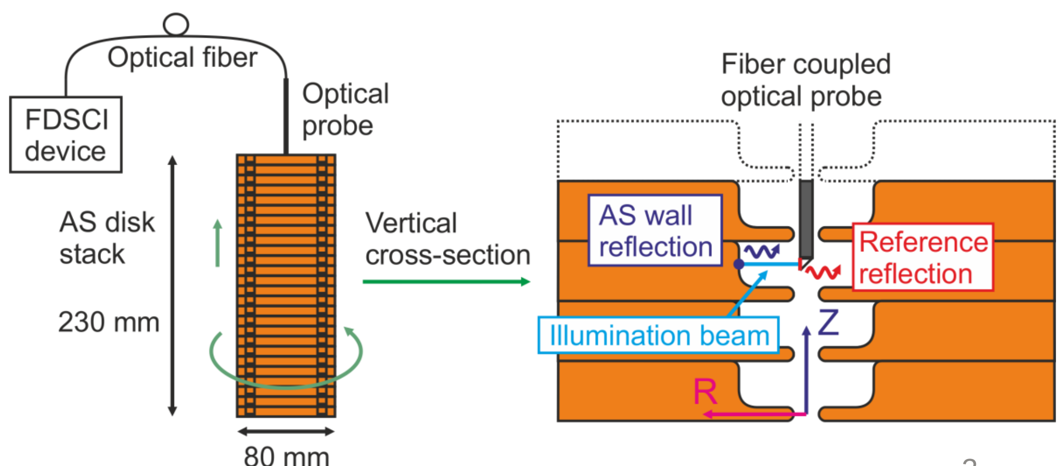
Introduction

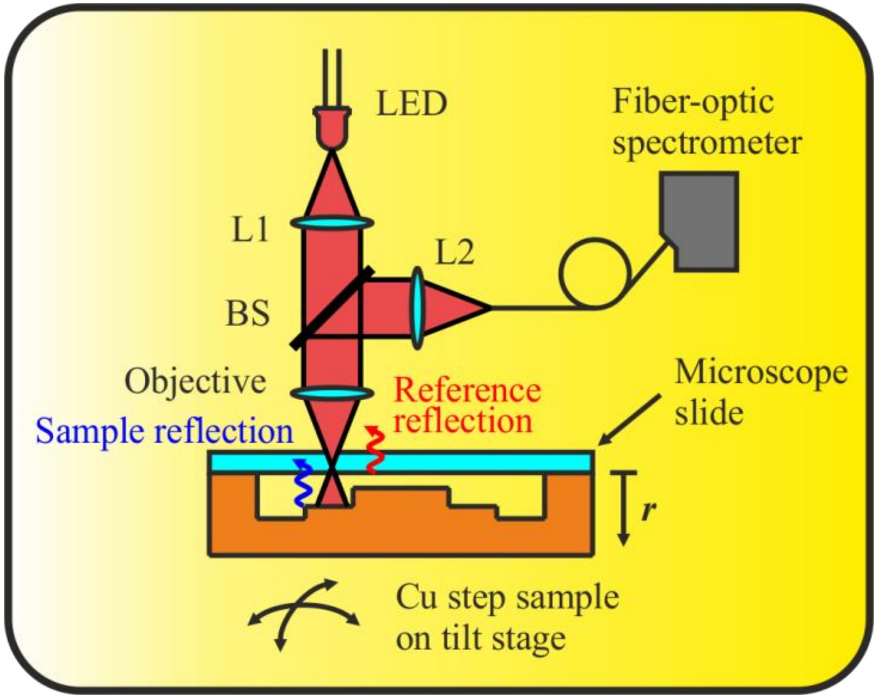
- The accelerator discs need to be aligned accurately.

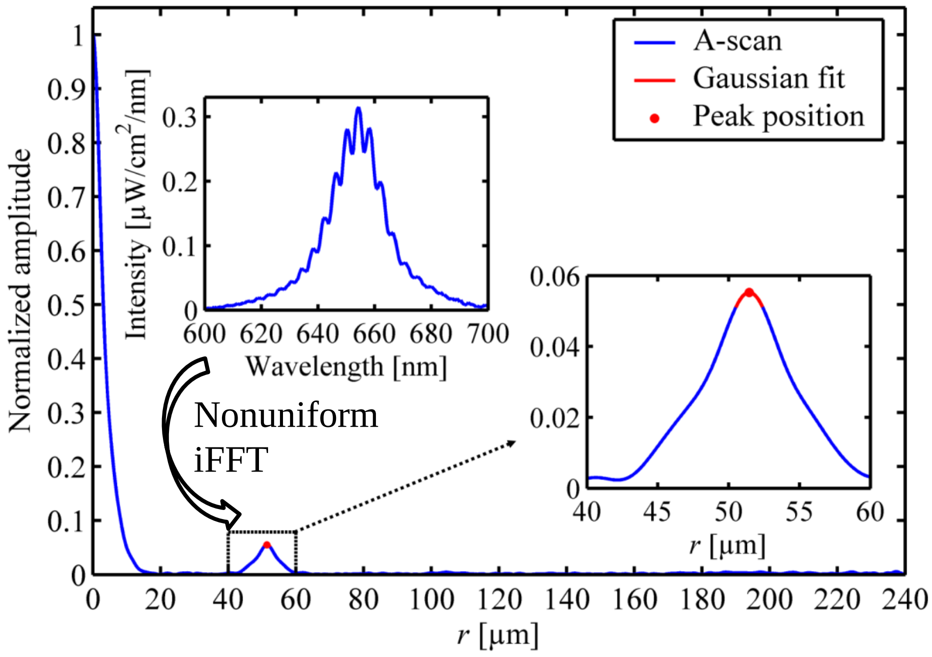
	Error in iris shape	Transversal offset	Tilt	Iris deformation
Shape error	 10 mm			
Tolerance	1 µm	5 µm	140 µrad	

- Sub-micron accuracy across 10 mm measurement range is required.
- Fourier Domain Short Coherence Interferometry (FDSCI) -technique



Design A

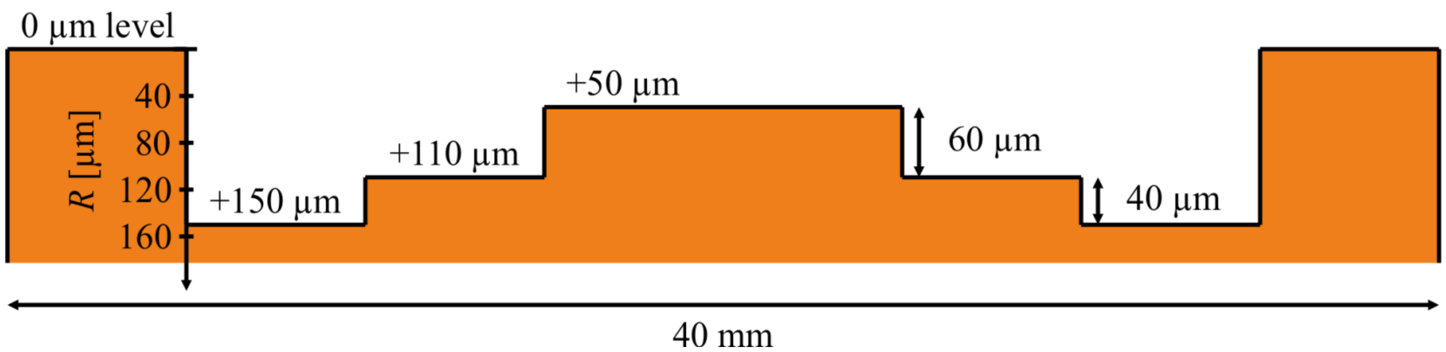




R. Montonen, I. Kassamakov, E. Hæggström, and K. Österberg, "Quantifying height of ultraprecisely machined steps on oxygen-free electronic copper disc using Fourier-domain short coherence interferometry," accepted for publication in *Optical Engineering*.

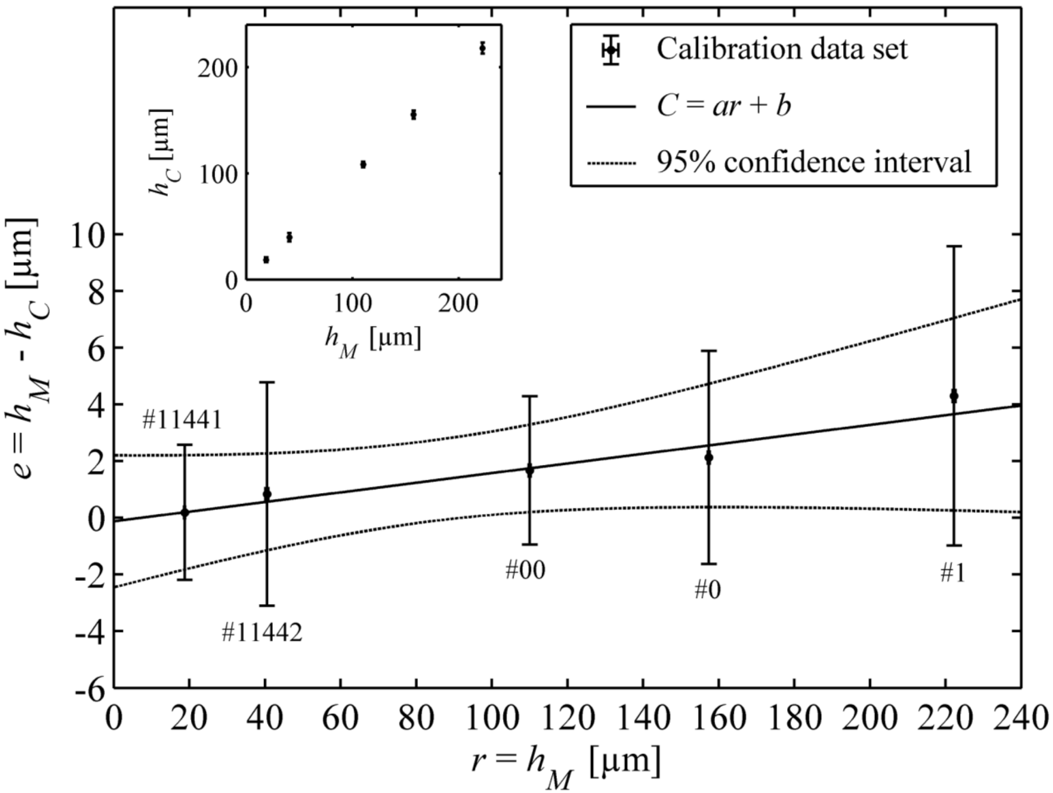
Measurement range $r_{max} \approx 240$ μm

Copper step sample



- 40 mm diameter oxygen-free electronic copper disc
- Surface roughness, $R_a \leq 25$ nm, flatness ≤2 μm
- Reference measurements done at CERN Metrology using a white light interferometer Veeco NT3300.

Calibration



R. Montonen, I. Kassamakov, E. Hæggström, and K. Österberg, "Calibration of Fourier domain short coherence interferometer for absolute distance measurements," *Appl. Opt.* **54**, 4635–4639 (2015).

Optical distance r in μm

Calibration function:
$C = (0.017r - 0.1)$ μm
at (22.0 ± 1.5) °C

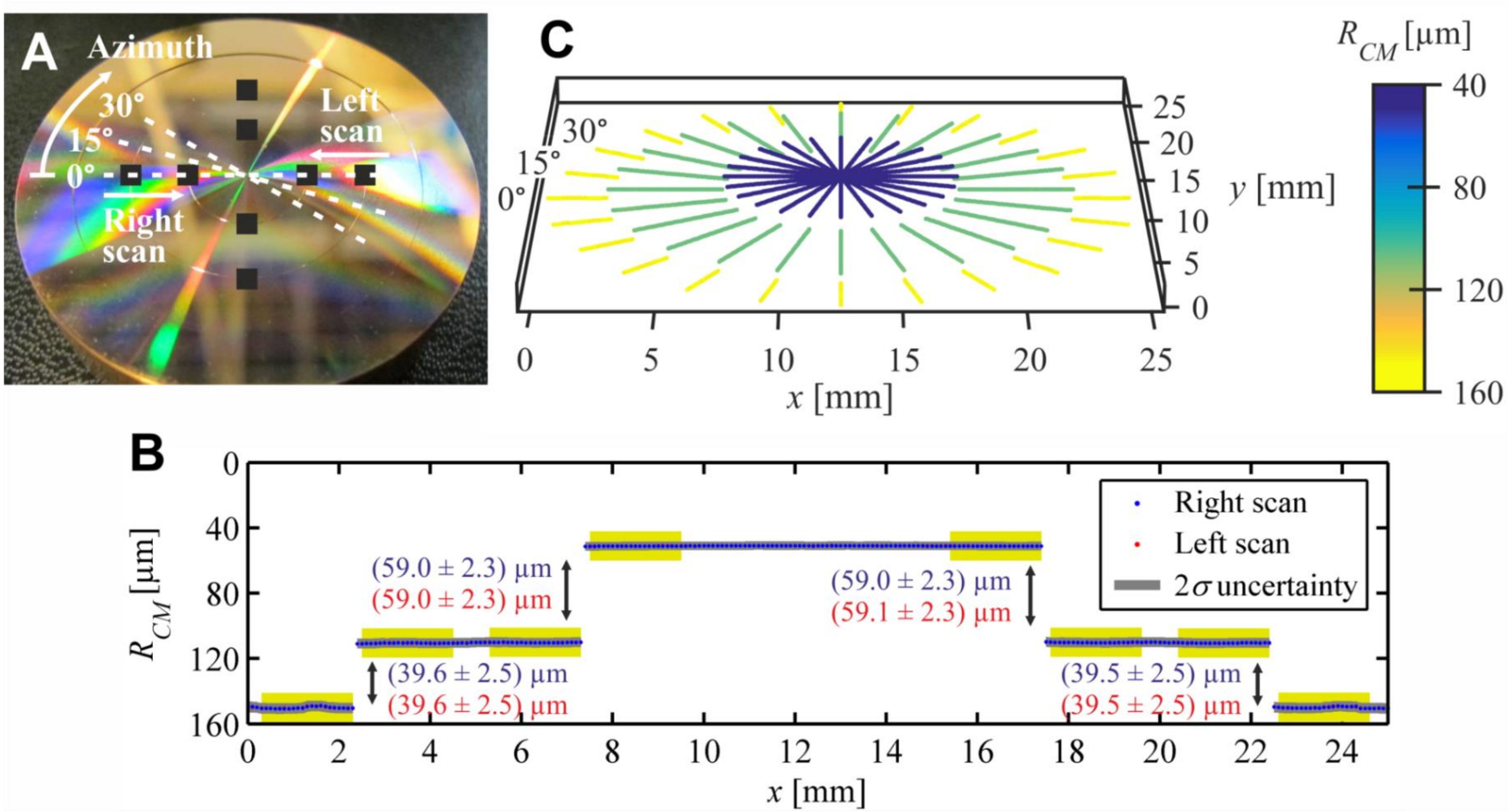
95% confidence level uncertainty:
$(5.9 \times 10^{-3}r + 2.3)$ μm

- Most significant uncertainty component in profile measurement

Calibrated optical distance:
$r_C = r - C$

Copper step sample results

New result for CLIC Workshop 2016



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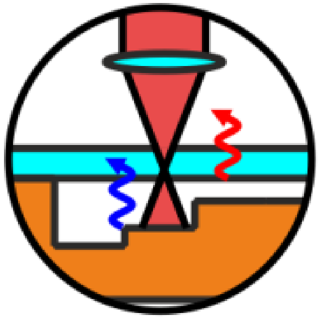
FDSCI	Veeco NT3300
(Step height ± 2σ) µm	
39.6 ± 2.6	40.27 ± 0.14
59.0 ± 2.3	60.44 ± 0.22

Correlated propagation of uncertainty to take into account systematic effects in scanning and calibration

Relevance to AS internal alignment study

- Common-path configuration cancels dispersion and polarization mismatch between the sample and reference light.

  → The achieved accuracy is retained when integrating a fiber-optic probe into the instrument.

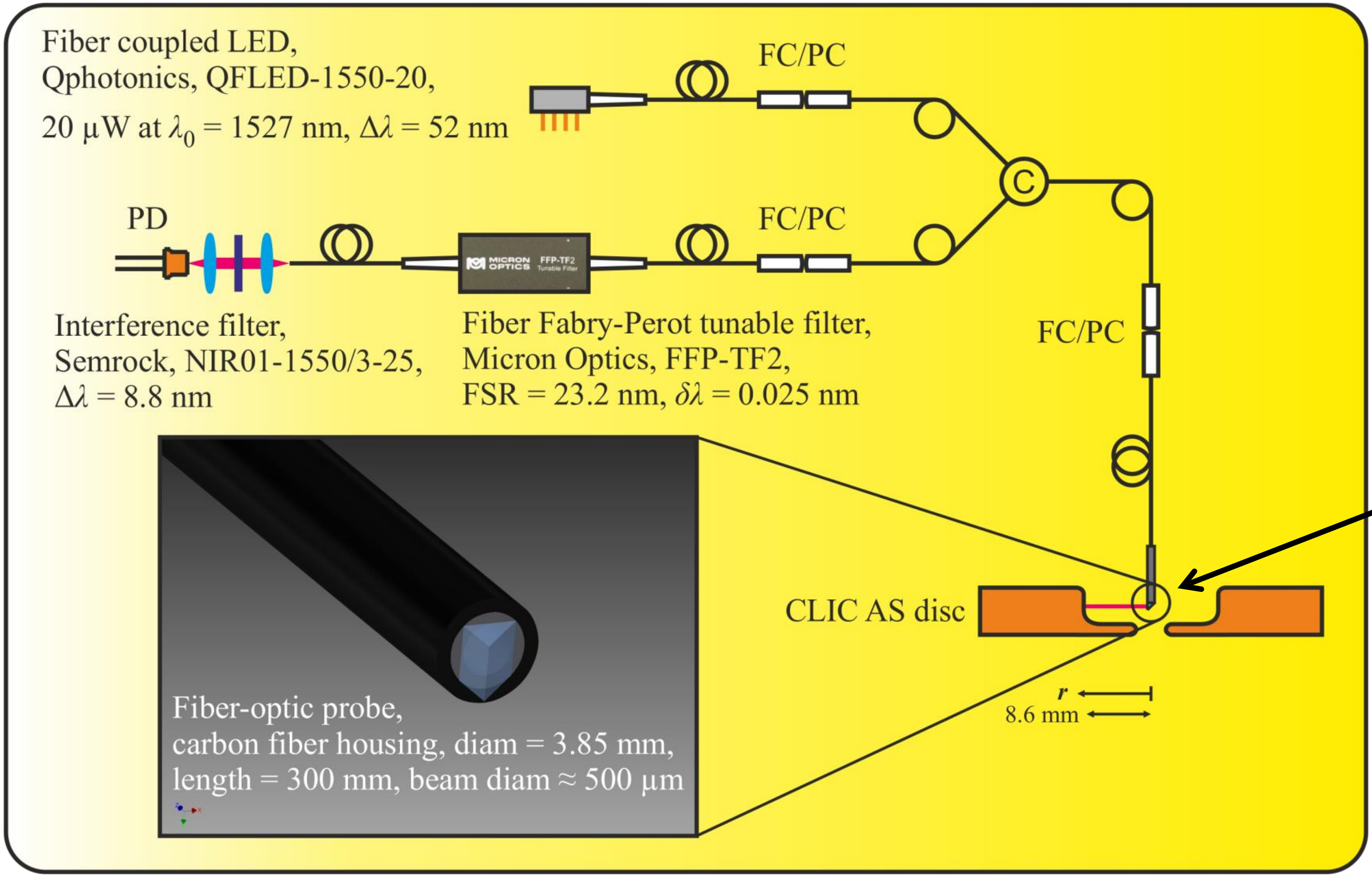


- The achieved uncertainty (2σ) is better than the 5 µm alignment tolerance.
  - When measuring a step from several millimeters distance the uncertainty is increased by ~1%.

Design B

Goal to reach 10 mm measurement range

Measurement range $r_{max} = \frac{\lambda_0^2}{4\delta\lambda} \approx 23\ \mathrm{mm}$



Probe tip positioning is a plausible problem

Conclusions

- The results show the feasibility of a fiber-optic FDSCI instrument to quantify the internal topography of CLIC AS with micrometer-level accuracy.
- Tunable Fabry-Perot cavity based instrument to reach measurement range across 10 mm currently under assembly.

Thank You

Thanks to Mr. Said Atieh and Mr. Dominique Pugnat from the Cern Engineering Department and CLIC team for providing us the copper step sample and for conducting the reference white light interferometry measurements.

Geometric distance uncertainty

Input quantity		Unit	Nominal value	Standard uncertainty $u(x_i)$	Sensitivity coefficient $\lvert c_i \rvert = \left\lvert \frac{\partial f}{\partial x_i} \right\rvert$	Uncertainty contribution $u_i(y) = \lvert c_i \rvert u(x_i)$ [µm]
Calibrated optical distance	r_C	µm	50.7	1.3	$\frac{1}{n_{air}}\left(1-\frac{\theta_r^2}{2}\right)(1+\alpha\Delta T)$	1.3
Tilt	θ_r	mrad	7.0	4.0	$\frac{r_C}{n_{air}}\theta_r(1+\alpha\Delta T)$	1.4×10^{-3}
Temperature difference	ΔT	K	-2.6	0.6	$\frac{r_C}{n_{air}}\left(1-\frac{\theta_r^2}{2}\right)\alpha$	5.0×10^{-4}
Coefficient of thermal expansion	α	10^{-6} K^{-1}	16.9	1.0	$\frac{r_C}{n_{air}}\left(1-\frac{\theta_r^2}{2}\right)\Delta T$	1.3×10^{-4}
Refractive index of air	n_{air}	–	1.0002667	0.5×10^{-6}	$\frac{r_C}{n_{air}^2}\left(1-\frac{\theta_r^2}{2}\right)(1+\alpha\Delta T)$	2.7×10^{-5}

Measurand		Function	Nominal value [µm]	Combined standard uncertainty $u_c(y) = (\sum_{i=1}^{N} u_i^2(y))^{1/2}$ [µm]	Expanded uncertainty $U = 2u_c(y)$ [µm]
Calibrated measured geometric distance	R_{CM}	$\frac{r_C}{n_{air}}\left(1-\frac{\theta_r^2}{2}\right)(1+\alpha\Delta T)$	50.7	**1.3**	2.6